Agricultural Systems 162 (2018) 154–163

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Modeling sustainable adaptation strategies toward a climate-smart agriculture in a Mediterranean watershed under projected climate change scenarios

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ARTICLE INFO

Keywords:
R'dom watershed
Climate change
SWAT model
Adaptation strategy
TOPSIS

ABSTRACT

Climate change projections for the Mediterranean region are predicting a significant rainfall decrease and an increase of temperatures. The consequences of these changes on food security and natural resources in this region might be very dramatic. Anticipating climate change impacts by improving agricultural systems efficiency is a critical need.

Therefore, this study was conducted to assess the vulnerability of water resources and performance of two major rainfed crops (Winter wheat & Sunflower) to climate change impact in R'dom watershed. The study aimed also, to evaluate some adaptation strategies to improve crops water productivities while preserving hydrologic resources. The study site is a typical Mediterranean agro-silvo-pastoral watershed in North-western Morocco, where water resources are facing an increasing demand.

Both hydrologic and plants growth modules of Soil and Water Assessment Tool Model (SWAT) have been calibrated and validated over the period 2004 to 2009. SWAT model and downscaled Global Circulation Model CNRM CM5 were used to simulate water yield and crops water productivities in 2031–2050 period under two Representative Concentration Pathways (RCP 4.5 and RCP 8.5). The RCM data revealed that the study area will experience important precipitation drop and mean temperature increase in the period 2031 to 2050. About 26.4% (± 2.89) decrease of basin water yield and up to 44.7% (± 9.03) drop down of crops water productivities were consequently predicted. After simulation of 5 combinations of no tillage and two early sowing dates' strategies, TOPSIS technique was used to prioritize strategies according to different management policies. Both no tillage and the 10 days early sowing strategies have stood out as two best adaptation strategies among the management policies evaluated as compared to business as usual.

1. Introduction

According to the revised 2017 report of United Nations regarding world population forecasts "The World Population Prospects" (UN, 2017), and with an increase rate of 83 million people per year, the world population will reach 9.8 billion people by 2050. Satisfying demand to feed this growing population is one of the major challenges of agriculture in the future (FAO, 2013).

Moreover, agricultural systems should face climate change impacts while reducing emission intensities and preserving the natural resources (FAO, 2013; Grafton et al., 2015; Steduto et al., 2012). Climate change is, certainly, already showing impacts on agriculture and food security especially in many world vulnerable areas such as the Mediterranean region (Abouabdillah et al., 2010; Bucak et al., 2017; De Gerolamo et al., 2015; Ons et al., 2015; Pascual et al., 2017; Senatore et al., 2010). Increasing incidence of extreme climatic events and unpredictable weather patterns was always the driving issue of low performing farming seasons in Morocco (extreme droughts in seasons: 1986–1987, 1991–1992, 1994–1995, 1998–2000 and floods in 2014, 2011, 2009…etc) (Balaghi and Dahan, 2015; Bouignane, 2010).

Climate-smart agriculture, as defined by FAO in 2010 Hague Conference on "Agriculture, Food Security and Climate Change", is offering an integrated framework that includes management policy and technical practices to achieve higher agricultural efficiency for food

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https://doi.org/10.1016/j.agsy.2018.01.024
Received 6 August 2017; Received in revised form 27 January 2018; Accepted 27 January 2018
Available online 08 February 2018
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security under climate change (FAO, 2013). One of the advantages of this concept is its location-specificity that is based on the technical limitations of the concerned area.

Because of the pessimistic future climate projections for Morocco (1.3 °C increase of yearly mean temperature and 11% drop of yearly average rainfall within 2050) the country will definitely be facing economical and food security related challenges (Balaghi and Dahan, 2015). The drought events of the seasons 1994/1995 and 1998/1999, where cereals production has dropped down by 60% and agriculture GDP decreased by 30%, illustrate how Morocco is threatened by climate change (Bouignane, 2010).

Agriculture is a key sector in the Moroccan economy, as it represents around 15% of the GDP (HCP, 2011) and employs about 43% of the workforce. The Moroccan government launched its strategic 2008–2020 vision for agriculture (Green Morocco Plan); to face major internal and external challenges and to increase farmers' incomes sustainably (MAPM, 2013). One of the strategies of this plan is to decrease cereal cropped surfaces by 22% and to increase the cereals production by 44% by 2020, which means more efficiency is needed from the production systems (Mrabet et al., 2012).

Rainfed crops water productivity in Morocco is generally low, due to technological constraints, to low rainfall in some areas and to improper management of rainy periods when they occur (Balaghi, 2014). In this study, winter wheat (*Triticum aestivum*) and sunflower (*Helianthus annuus*) crops have been considered due to their roles in the world food security programs and because cereals and oilseed grains are the major imported food by Morocco despite their local production (around 50% of the total imported agricultural product in terms of value in 2012 (MAPM, 2013)).

In this paper, SWAT, a semi-distributed model has been used to predict both hydrological processes and water productivity of two major crops under climate change projections within an agro-silvo-pastoral watershed in Morocco. The main objectives of this work are: (i) to model hydrology and plants growth in the study watershed, (ii) to investigate the potential climate change impact on hydrologic resources and crops water productivity, and (iii) to investigate sustainable adaptation strategies under different management policies scenarios.

2. Materials and methods

2.1. Study site

This study was conducted on a watershed (R'dom) located in North western Morocco, laying partly in the South on the Sais plateau and partly in the North on the Pre-Rif ridges, with an area of about 1990 km^2. This watershed is considered among the main sub-watersheds of the Sebou river basin (one of the largest basins in the country). Both Meknes and Sidi Kacem cities are located within the watershed. Souk Elhad gauge (34° 17′ 37” N; 5° 46′ 2” W) represents the watershed outlet (Fig. 1).

The R'dom climate is Semi-arid, Average annual precipitation is about 467 mm, and the rainiest seasons are winter (44%) and spring (25%). Average annual temperature is 16.2 °C, with January being the coldest month and August the warmest one (Zian, 2011). The R'dom river is intermittent, with mean annual discharge of 2.1 m^3/s measured at the unique flow-gauge station of Souk Elhad (Brouziyne et al., 2017b).

The watershed topography is variable; altitudes are ranging from 32 m to 1800 m (Fig. 1). Variability is reported also on soil types across the watershed; soils in the Northern part of the watershed are sandy and well drained, and are more clay-loamy with high swelling activity in the South (Brouziyne et al., 2017b).

The main socio-economic activities in the area rely on agriculture, with mixed forest-pasture system. Cereals, legumes and oil seeds are the main cultivated crops in the area (around 40% of the total cropped lands).

Despite the increasing water demand (mainly due to agricultural activities), the water resources in this watershed are characterized by a massive spatial and temporal variability and uneven distribution within the landscape (Brouziyne et al., 2017a).

3. SWAT model

3.1. Model presentation

The Soil and Water Assessment Tool (SWAT) developed by the US Department of Agriculture (Agricultural Research Services) (Arnold et al., 2011) was adopted for the present study. The main components of the model are climate, hydrology, erosion, soil temperature, plant growth, nutrients, pesticides, land management, channel and reservoir routing.

The watershed is partitioned, according to topography, into a number of sub-basins connected by a stream network. Each sub-basin is further divided into several homogonous Hydrological Response Units (HRU) based on soil characteristics, cropping pattern and management practices. HRUs are used by SWAT model as units where water budget and crops yields are predicted (Arnold et al., 2012).

SWAT uses a simplified version of Erosion Productivity Impact Calculator model (EPIC) (Neitsch et al., 2002) to simulate crop growth process and yield. In EPIC model, plant development is simulated based on actual evapotranspiration, leaf area development, light interception and its conversion to biomass and yield. Plant growth can be limited by temperature, water, Nitrogen or Phosphorous stress. For the study of carbon dioxide climate change effects, carbon fertilization is accounted through different fundamental processes such as the radiation use efficiency and the canopy resistance (Neitsch et al., 2002).

3.2. Model parameterization

Watershed delineation tool of ArcSWAT has been used to delineate sub-basins based on Digital Elevation Model (DEM) data. 27 connected sub-watersheds were identified and stream network of R'dom basin was defined. Watershed outlet was manually defined to match the geographic location of the Souk El Had gauge station (Fig. 1) where flow out processes were monitored to compare measured and predicted flows.

A SWAT soil map has been developed based on available survey reports and ministry of agriculture maps covering the basin at a 1:50,000 scale. Data included soil texture, soil hydrological group, number of soil layers, organic carbon, clay, sand and silt contents, erodibility factor, pH and electrical conductivity, …etc). SWAT land use map was created based on image scenes from LANDSAT8 (captured April 2015) that were classified using several ground truths sites.

Farming practices patterns were added to the model according to the agricultural practices applied in the study watershed, especially the ones with high potential effect on water cycle and crop performance such as: sowing and harvest dates, tillage operation features, fertilization operation. In this study optimal nutrient quantities were supplied to crops and were not considered as limitating factors to plant growth; only heat and water stress (due to potential climate change impact) were taken into account. Winter wheat and sunflower were chosen as target crops for this study. The conventional practices used are given in Table 1 (Ait Houssa et al., 2014; Bamouh, 1993; Si Bennasseur, 2014).

In order to reflect, as much as possible, the real crops behaviours against the watershed conditions some cultivar characteristics of the selected crops were amended based on previous studies (Aboudrar et al., 2004; Balaghi and Mohammed, 1993; Jlibene, 2009; Zwart, 2010) (Table 2).

Observed weather parameters were imported into SWAT model, which includes daily maximal and minimal temperature from 6 weather stations and daily rainfall from 4 recording stations within and around the watershed (Fig. 1). The data series were ranging from January 2003 to December 2010.

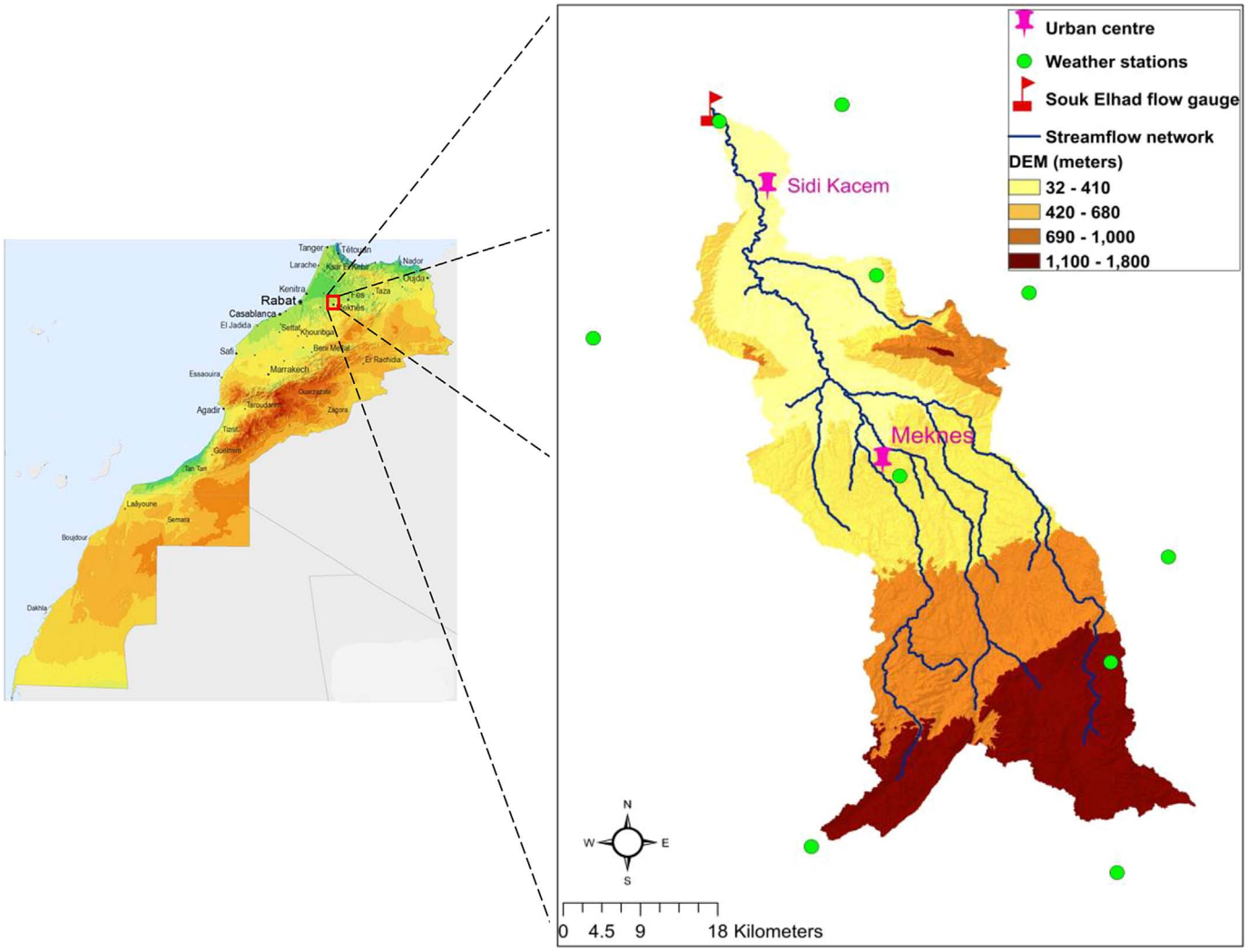

Fig. 1. Localisation, digital elevation model and weather stations of R'dom watershed.

Table 1
Considered farming patterns of winter wheat and sunflower in SWAT model.

	Winter wheat	Sunflower
Sowing date	1st November	20th March
Harvest date	1st June	1st July
Tillage techniques	Chisel plow + Disk harrow	Disc plow + Disc harrow
Fertilization N-P-K (kg/Ha)	90-70-80	110-30-40

3.3. Model calibration and validation

Many computational researchers are focusing on developing automated calibration methods; but several specialists are still believing that the manual calibration approach is offering a “safe” choice. Despite the intensive efforts needed to become familiar with the model response, the manual calibration method is involving step-by-step control of the mass balances (Van Liew et al., 2005).

To build a solid background for further research projects on this area, and as no previous SWAT application in R'dom watershed was recorded; significant efforts were spent to push the model to replicate the processes occurring in the study watershed. This was aimed through a site specific sensitivity analysis, the use of high resolution input data and the selection of manual approach to calibrate the model.

Calibration of the hydrologic module was performed by modifying the most sensitive input parameters based on the relative sensitivity method described by Haan et al. (1995):

$$S_r = [(O_{P+\Delta P} - O_{P-\Delta P})/O_P)]/(2\Delta P/P)] \quad (1)$$

where:

S_r: relative sensitivity;
$O_{P+\Delta P}$: model outputs with the input parameter being studied, set at

Table 2
Amended plants growth parameters in SWAT database for Wheat and Sunflower.

SWAT parameters		Range	Winter Wheat		Sunflower	
			Default value	Amended value	Default value	Amended value
T base	Minimum T base (C°)	0 to 30	0	6	6	10
T opt	Optimal T for plant growth(C°)	0 to 40	18	20	25	25
RDMX	Maximum root depth (m)	0 to 3	1.3	1.0	2.0	2.2
CHTMX	Maximum canopy height (m)	0 to 10	0.9	1.8	2.5	2.5

Table 3
Plants growth parameters adjusted during yield calibration.

SWAT Parameters		Range	Winter Wheat		Sunflower	
			Default value	Calibration value	Default value	Calibration value
HVSTI	Harvest index	0 to 1	0.40	0.50	0.30	0.35
WSYF	Lower limit of HVSTI	0 to 1	0.20	0.45	0.20	0.20
BLAI	Maximum potential leaf area index	1 to 12	4	4	3	4
BIO_E	Radiation use efficiency	0 to 100	30	35	46	42
EXT_COEF	Light extinction coefficient	0 to 1	0.65	0.60	0.90	0.70

the base value (equal to the initial calibrated value) plus a specified percentage (often taken to be between 10% and 25%);
$O_{P\text{-}\Delta P}$: model outputs with the input parameter being studied, set at base minus a specified percentage (often taken to be between 10% and 25%);
O_p: Model output with input parameter set at the base value
ΔP: The prescribed absolute change in the value of the input parameter
P: The initial calibrated value (base value) of the input parameter

Recorded daily streamflow data, from January 2004 to December 2009, in the watershed outlet (Souk Elhad gauge) were compared during the calibration iterations to the simulated daily discharge at the same outlet.

Since the mean yearly rainfall of R'dom watershed is 467 mm, the simulation period included a dry year (2006 with 307 mm rainfall) and wet year (2009 with more than 620 mm rainfall). The simulation period was not very large (due to lack of long-time recording series), but it offered SWAT model the opportunity to be initiated to both flash-runoff and channel dry-up conditions.

The Nash-Sutcliffe coefficient (NSE), the determination coefficient (R^2) and percent bias (PBIAS) have been taken as maximal agreement indicators between observed and predicted flow during both calibration and validation processes:

$$NSE = 1 - \frac{\sum_{i=1}^{n} (Oi - Pi)^2}{\sum_{i=1}^{n} (Oi - O_{avg})^2} \quad (2)$$

and:

$$R^2 = \left(\frac{\sum_{i=1}^{n} (O_i - O_{avg})(P_i - P_{avg})}{[\sum_{i=1}^{n} (O_i - O_{avg})^2 \sum_{i=1}^{n} (P_i - P_{avg})^2]^{0.5}} \right)^2 \quad (3)$$

and:

$$PBIAS = \frac{\sum_{i=1}^{n} (O_i - P_i) 100}{\sum_{i=1}^{n} O_i} \quad (4)$$

where:

O_i: the observed parameter's value for time period i
P_i: the simulated parameter's value for the same period
O_{avg}: the mean of observed parameter's values per time period
n: the number of time intervals

The NSE represents the model's precision in simulating the flood streamflow; the maximum NSE value of 1.0 occurs if predicted values are perfectly matching measured ones (Feyereisen et al., 2007; Shi et al., 2011). The R^2 provides how well the correlation between measured and simulated values is (Grimaldi et al., 2015).

PBIAS determines average tendency of simulated data to be greater or lesser than their observed counterparts, the ideal value of PBIAS is zero (Moriasi et al., 2007). This factor includes subjectively conceptual model uncertainty (due to the simplification of processes), input uncertainty (due to potential errors in input data), and parameter uncertainty (due to inherent non-uniqueness of parameters in inverse modeling) (De Gerolamo et al., 2016). Moriasi et al. (2012) defined SWAT model performance for streamflow simulation as "satisfactory", for observed data of typical uncertainty, if PBIAS ± 25%.

The SWAT model was run over January 2004 to December 2009 period, the first two years were used to spin up the model; 2006 and 2007 were dedicated to calibration and 2008 to 2009 was left for validation process.

During calibration and validation processes of the flow component, simulated daily discharge was compared to the observed one that has been obtained from the managing river basin agency (ABHS).

SWAT crops module was calibrated as well using the same manual approach after reviewing the main sensitive plants growth parameters (Table 3) in previous similar studies (Aaron et al., 2015; Arnold et al., 2012; Hirich et al., 2012; Kang et al., 2009; Sinnathamby et al., 2016; Srinivasan et al., 2010). Some parameters have been selected to be adjusted (Table 3) and calibration was pursued by taking NSE, PBIAS and R^2 as model calibration performance indicators. The observed yearly average yields of the selected crops (from 2004 to 2009) for the R'dom were obtained from the regional Ministry of Agriculture's departments, and were compared to simulated yearly average yields during calibration and validation.

4. Future climate projections

In order to assess future climate projections in the study site, dynamically downscaled output data from the French Global Climate Model CNRM-CM5 (used in the 5th version of the Coupled Model Intercomparison Project (CMIP5)) were used. Data for this model was derived from CORDEX-Europe domain at 12.5 km horizontal resolution. The CNRM CM5 is an earth system model incorporating integrated modeling components and has been previously successfully used in future climate simulations over Morocco (Balaghi, 2017; Tramblay et al., 2013).

The used regional climate model in this study is: CLMcom-CCLM4–8-17 model from the Climate Limited-area Modelling Community (CLM-Community).

Two Representative Concentration Pathways (RCPs) were selected, RCP 4.5 as a realistic emission scenario and RCP 8.5 as the pessimistic one. Baseline time series for both daily temperature (max and min) and rainfall data were from January 1986 to December 2005, for future datasets the period 2031 to 2050 was considered.

Daily observed data from R'dom watershed meteorological stations were used to prepare the simulated climate change data by applying bias correction procedures; CMhyd[1] software (Rathjens et al., 2016) was used for this purpose.

Bias correction is generally used to minimize discrepancy and uncertainty between observed and simulated climate variables using

[1] CMhyd is a tool that can be used to extract and bias-correct data obtained from global and regional climate models. It was designed to provide simulated data that can be considered representative for the location of the gauges used in a watershed model setup (Rathjens et al., 2016).

empirical relationships between large-scale features and local conditions assuming that these relations stay the same in changing climate (Piani et al., 2009). In this study, linear scaling and variance scaling approaches were used to analyze future raw dynamically downscaled precipitation and temperature data respectively, after reviewing diverse studies where these two methods demonstrated high deviation correction performance under similar conditions (Amengual et al., 2012; Hwang and Yoon, 1981; Jaw et al., 2015; Maraun, 2013; Teutschbein and Seibert, 2012). Linear scaling method aims to perfectly match the monthly corrected values with that of observed ones; precipitation is typically corrected with a multiplier factor (Hwang et al., 2013). The variance scaling method is commonly known for being able to correct both mean and variance of normally distributed variables (such as temperature) (Amengual et al., 2012).

5. Adaptation strategies

Two adaptation strategies have been investigated in this study, no tillage and early sowing date, as potential sustainable methods that might make the farming pattern in R'dom more climate-smart against the potential climate change impact in the future.

Many studies and experimentations proved the benefits of no-tillage strategy on water use efficiency and soils quality (Abdelwahab et al., 2016; Aboudrar et al., 2004; Mrabet, 2001). Sowing or planting without ploughing the soil preserves the soil moisture and conserve the biotic systems that generally take place in the soil (Mrabet et al., 2012; Ullrich and Volk, 2009). Shifting the conventional sowing dates to earlier ones gives the crops chance to get benefit from the soil moisture (after last rains) and to avoid warm periods at the season end (Ceglar and Kajfez, 2011; Eltigani, 2015).

The selection of these two strategies is supported by their easy technical applicability and their integrability within the general sustainability policies of the department for agriculture. The other point behind putting these two adaptation strategies forward in this study is the positive results achieved in similar studies in Morocco and in similar areas (Abdelwahab et al., 2016; Aboudrar et al., 2004; Balaghi, 2014; Debaek et al., 2016; Mrabet et al., 2012; Waidler et al., 2011; Zwart, 2010).

Overall, 5 different combinations of adaptations strategies were considered: No tillage (NT), 10 and 20 early sowing days compared to actual dates (ESD-10 and ESD-20 respectively), and a combination of no tillage and sowing dates change: NT + ESD-10 and NT + ESD-20.

6. Criteria & ranking of adaptation strategies

Two effectiveness indicators of the reviewed adaptation strategies were considered in this study, Water Yield (WYLD) at the basin outlet and Crop Water Productivity (CWP). The WYLD offers the opportunity to assess the impact of the adaptation strategies on the overall hydrologic resources in the basin and the CWP advises about how the implemented adaptation strategies can help produce more food with less water. Crop water productivity (kg/m^3) has been calculated as crop yield (kg/ha) over actual evapotranspiration (m^3/ha).

The Technique for Orders Preferences by Similarity to the Ideal Solution (TOPSIS) method (Hwang and Yoon, 1981), was selected as a multi-criteria decision making technique to find out the best adaptation strategies according to the expected goals. The TOPSIS technique is based on the concept that the ideal strategy has the best value for all standardized criteria, whereas the negative strategy ideal is the one with all of the worst standardized values. A TOPSIS solution is defined as the strategy that is simultaneously farthest from the negative ideal strategy and closest to the ideal one (Sang-Mook et al., 2013).

The standardized criteria values are calculated by dividing each value by the sum of the criteria values for all alternatives and is based on separation measures for each alternative from the positive ideal (S_i^*) and negative ideal (S_i^-) solutions(Jun et al., 2011). The relative closeness of alternative A_t with respect to A^* (ideal alternative) in this method is defined as:

$$RC_i^* = \frac{S_i^-}{S_i^* + S_i^-},\ i = 1, 2, \ldots, m \tag{5}$$

with,

$$S_i^* = \sqrt{\sum_{j=1}^{m} (v_{ij} - v_j^*)^2},\ j = 1, 2, \ldots, m \tag{6}$$

$$S_i^- = \sqrt{\sum_{j=1}^{m} (v_{ij} - v_j^-)^2},\ j = 1, 2, \ldots, m \tag{7}$$

where v_{ij} is the weighted standardized criterion value of the ith alternative that is calculated by multiplying standardized criterion value by the corresponding weight, and v_j^* is the ideal value and v_j^- is the negative ideal value for the jth criterion (Rezaei Zaman et al., 2016). Ranking of alternatives in this method is carried out according to the value of RC_i^*.

7. Results & discussion

7.1. Baseline SWAT simulation

SWAT model was run for the period 2004 to 2009, as baseline period, for both hydrological and crop yield components.

7.2. Hydrologic simulation

SWAT model has showed acceptable performance on replicating the hydrological processes occurring in the R'dom watershed in the daily time step, with an NSE of 0.58, an R^2 equal to 0.79 and a PBIAS equal to 19% for the calibration period. However, during validation period NSE was equal to 0.65, R^2 reached 0.73 and the PBIAS was 13%. Taking into consideration the Semi-arid context of the study site and based on many similar studies of intermittent rivers systems, these results were considered satisfactory (Abouabdillah et al., 2014; De Gerolamo et al., 2016).

Hydrographs in Fig. 2 show that predicted discharge at the watershed outlet follows the pattern of the observed one during calibration and validation process.

7.3. Crop yield simulation

The Table 4 shows results of winter wheat and sunflower yields calibration and validation results over the period 2004 to 2009 (with two years spin up period). The simulated crop yields were compared to the yearly average yields recorded in the area by the regional department of Agriculture over the same period (2004 to 2009) (DPA, 2017).

After calibration and validation, the mean sunflower and wheat simulated crops yields are in good agreement with the recorded yield during the period 2004 to 2009.

8. Future climate simulation

The analysis of the downscaled RCM data revealed that the area will definitely experience rainfall drop and mean temperature increase in the period 2031 to 2050 for both emission scenarios. In general, a significant rainfall decrease is expected for both scenarios, with more incidence in the RCP8.5 scenario with 26% drop of annual rainfall is predicted with a standard deviation of 11.73% (Table 5). Winter and spring, the main growing seasons for the selected crops, will be the most affected by rainfall decrease in both scenarios. An important mean temperature increase is also expected: +1.1 °C and 1.7 °C respectively for RCP4.5 and RCP8.5 (with 0.19 °C and 0.35 °C respectively, as standard deviations). Winter, an important season for cereals, will be

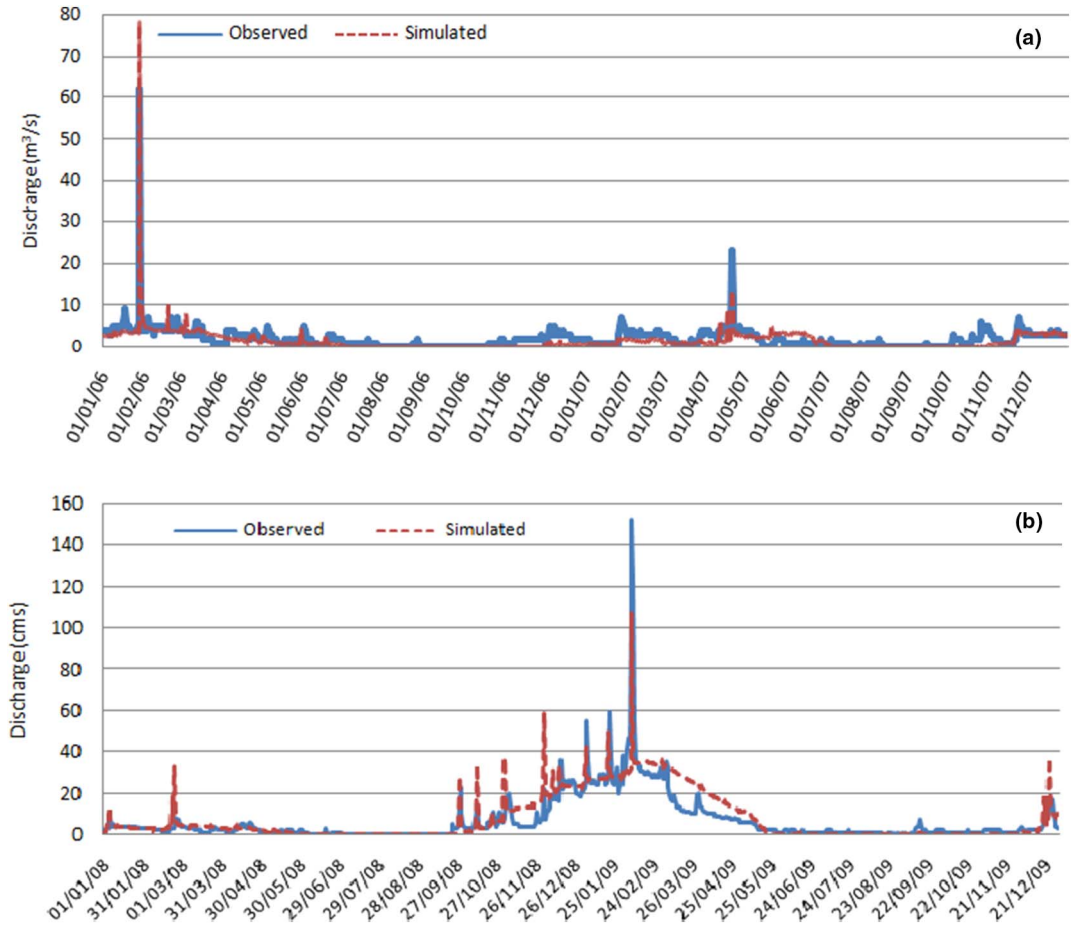

Fig. 2. (a) Daily calibration hydrograph; (b) Daily validation hydrograph.

Table 4
Performance indicators of yields calibration and validation.

	Calibration				Validation			
	Period	NSE	R^2	PBIAS	Period	NSE	R^2	PBIAS
Winter wheat	2006 and 2007	0.70	0.81	16%	2008 and 2009	0.61	0.73	22%
Sunflower	2006 and 2007	0.55	0.68	12%	2008 and 2009	0.68	0.80	16%

the most significantly affected with a major change of +3.4 °C (± 0.52) in January (Table 5).

Analyzing the standard deviation across the projection period provides information regarding the efficacy of bias correction and uncertainty control. For instance, most of standard deviation values were lower than mean temperature and precipitation changes under both RCPs.

Relatively high deviations were observed on the monthly precipitation changes indicating high variability across years because of the intermittence between successive wet and successive dry periods.

9. Adaptation strategies analysis

Table 6 is summarizing the winter wheat and sunflower crops water productivity and basin water balance responses to the different adaptation strategies under the RCP4.5 and RCP8.5 emissions scenarios.

Table 5
Mean precipitation and temperature changes in climate change scenarios (2031–2050).

		Precipitation change (%) (Standard deviation)		Temperature change (°C) (standard deviation)	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Winter	December	−38 (11.33)	−37 (19.35)	+0.6 (0.18)	+0.3 (0.24)
	January	−30 (13.02)	−49 (18.07)	+3.4 (0.38)	+3.4 (0.52)
	February	−25 (11.18)	−32 (13.76)	+2.2 (0.26)	+2.5 (0.40)
Spring	March	−12 (4.96)	−23 (16.88)	+0.7 (0.19)	+0.3 (0.18)
	April	−13 (9.62)	−17 (8.71)	+0.0 (0.10)	+0.5 (0.23)
	May	−32 (5.32)	−41 (9.09)	+0.7 (0.18)	+2.0 (0.38)
Summer	June	−10 (3.18)	−24 (4.56)	+1.4 (0.22)	+3.4 (0.48)
	July	+38 (3.85)	+44 (9. 08)	+0.0 (0.12)	+2.3 (0.43)
	August	+43 (6.10)	−38 (7.18)	+1.6 (0.20)	+1.3 (0.40)
Fall	September	−8 (8.14)	−8 (7.22)	+1.2 (0.23)	+1.2 (0.30)
	October	−6 (10.88)	+10 (12.60)	+1.1 (0.18)	+1.9 (0.38)
	November	−9 (11.51)	−22 (14.28)	+0.1 (0.08)	+1.0 (0.26)
		Averages (%) (standard deviation)		Averages (°C) (standard deviation)	
		−19 (8.27)	−26.1 (11.73)	1.1 (0.19)	1.7 (0.35)

9.1. Business as usual

"Business as usual" (BAU) scenario, referred to keeping the current crops management scheme (conventional tillage and the same sowing dates) during the period 2031–2050, was included in the comparison

Table 6
Comparison of indicators in BAU scenario to the baseline ones.

	Baseline	RCP4.5		RCP8.5	
	Simulated value	Simulated value	Change (Standard deviation)	Simulated value	Change (Standard deviation)
Wheat CWP	0.69 kg/m^3	0.56 kg/m^3	−18.8% (2.02)	0.54 kg/m^3	−21.7% (3.96)
Sunflower CWP	0.38 kg/m^3	0.32 kg/m^3	−15.7% (4.65)	0.21 kg/m^3	−44.7% (9.03)
WYLD	89.20 mm	71.17 mm	−20.2% (0.18)	65.67 mm	−26.4% (2.89)

Table 7
Comparison of indicators in No tillage scenario to the ones under BAU scenario during 2031–2050.

	RCP4.5		RCP8.5	
	Simulated value	Change (Standard deviation)	Simulated value	Change (Standard deviation)
Wheat CWP	0.68 kg/m^3	21.4% (5.23)	0.63 kg/m^3	16.7% (3.63)
Sunflower CWP	0.50 kg/m^3	56.3% (8.19)	0.33 kg/m^3	57.1% (4.16)
WYLD	71.7 mm	0.7% (0.32)	66.0 mm	0.5% (0.40)

with the selected adaptation strategies.

For this scenario, and according to the results showed in the Table 6, an important decrease of water balance and crops water productivity are expected under both considered RCPs.

Both crops will experience a decrease of their CWPs in both scenarios. The biggest change is observed on sunflower in scenario RCP8.5 (44.7% ± 9.03 lower than the baseline situation). According to the calendar of sunflower growth in the study area the flowering and grains filling stages, very important growth stages for sunflower (Gimeno et al., 1989),will be affected by the mean temperature increase in April and May (with high evaporative demand) especially in RCP8.5 (Table 5). The low crop water productivity of sunflower especially in RCP8.5 can be linked also to the significant rainfall decrease from March to May covering germination, flowering and grains filling stages (Table 5) which are very sensitive growth stages to water stress (Bamouh et al., 2001).

Regarding winter wheat, CWPs decreases of 18.8% and 21.7% are expected in RCPs 4.5 and 8.5 respectively (with standard deviations of 2.02% and 4.65% respectively). The significant rainfall decrease in winter (December to February) when wheat tillers development and floral initiation occur, which are very responsive growth stages to moisture stress (Turner, 1997), is the main reason behind the predicted wheat water productivity decline.

As comparison between the two crops, these results revealed that winter wheat is less vulnerable to climate change compared to sunflower in the R'dom watershed which confirms the findings of Mrabet (2001), Steduto et al. (2012) and Zwart (2010).

The aforementioned decrease of rainfall during the rainy periods and the increase of mean temperatures have significantly affected the water availability and distribution in the R'dom watershed. About 20% ± 0.18 and 26% ± 2.89 decrease of water yield are expected at the watershed outlet during the study period under the RCP4.5 and RCP8.5 respectively.

All standard deviation values were below their respective CWP and WYLD changes giving confidence on the interpretation of the results.

9.2. No tillage strategy

The results of the no tillage (Table 7) demonstrate that this strategy is indeed very effective on agricultural indicator as a CWP increase of 57.1% (standard deviation of 4.16%) is achievable in the case of sunflower under RCP 8.5 scenario (in comparison with the BAU scenario). For wheat, the NT strategy leaded to CWP increase of 21.4% ± 5.23 and 16.7% ± 3.63 under RCP 4.5 and RCP 8.5 emission scenarios respectively.

In overall, similar results were found by El Gherras and Idrissi (2006) and Bourarach et al. (1998) in their works under semi-arid context.

Little increase on water availability is observed after the application of this strategy, 0.7% ± 0.32 increase of WYLD in RCP4.5 and 0.5% in RCP8.5 (standard deviations of 0.32% and 0.5% respectively).

9.3. Sowing dates change strategies

The predicted changes shown earlier in Table 5 corroborate the choice of the strategies of advancing sowing dates by 10 days and 20 days earlier than the conventional (Table 8):

- For winter wheat, as germination is one of the highly sensitive wheat growing stages to water stress (Fischer, 1979), shifting germination stage to more rainy period (October) will avoid the significant decrease of rainfall is expected in November. This shift should also save the grain filling stage from the expected temperature increase in May and June that may lead to early senescence and grain yield reduction (Passioura, 1977).
- For Sunflower, the shift would avoid as much as possible the predicted high temperatures in late spring-early summer (especially in May and June) when grains filling is occurring and that can have dramatic incidence on the crop yield (Villalobos and Fereres, 1990).

Applying these strategies under the two RCPs through the 2031 to 2050 period, more than 14% ± 2.56 increase of wheat water productivity would be achieved in the RCP4.5 and RCP8.5 scenarios when

Table 8
Comparison of indicators in early sowing dates scenarios to the ones under BAU scenario during 2031–2050.

	ESD-10				ESD-20			
	RCP4.5		RCP8.5		RCP4.5		RCP8.5	
	Simulated value	Change (Standard deviation)	Simulated value	Change (Standard deviation)	Simulated value	Change (Standard deviation)	Simulated value	Change (Standard deviation)
Wheat CWP	0.64 kg/m^3	14.3% (2.56)	0.62 kg/m^3	14.8% (8.02)	0.59 kg/m^3	5.4% (2.80)	0.50 kg/m^3	−7.4% (6.53)
Sunflower CWP	0.33 kg/m^3	3.1% (3.33)	0.20 kg/m^3	−4.8% (3.30)	0.19 kg/m^3	−40.6% (7.96)	0.16 kg/m^3	−23.8% (8.66)
WYLD	72.57 mm	2.0% (0.56)	66.8 mm	1.7% (0.30)	73.9 mm	3.8% (0.40)	67.9 mm	3.4% (0.56)

Table 9
Comparison of indicators in No tillage and early sowing dates scenarios to the ones under BAU scenario during 2031–2050.

	NT + ESD-10				NT + ESD-20			
	RCP4.5		RCP8.5		RCP4.5		RCP8.5	
	Simulated value	Change (Standard deviation)	Simulated value	Change (Standard deviation)	Simulated value	Change (Standard deviation)	Simulated value	Change (Standard deviation)
Wheat CWP	0.70 kg/m^3	25.0% (2.30)	0.64 kg/m^3	18.5% (5.98)	0.56 kg/m^3	0.0% (3.20)	0.52 kg/m^3	−3.7% (4.77)
Sunflower CWP	0.33 kg/m^3	3.1% (3.22)	0.21 kg/m^3	0.0% (4.18)	0.19 kg/m^3	−40.6% (11.89)	0.16 kg/m3	−23.8% (6.38)
WYLD	72.21 mm	1.5% (0.29)	67 mm	2.0% (0.97)	74.01 mm	4.0% (0.89)	69.88 mm	6.4% (0.32)

Table 10
The considered management policies and weights of indicators.

		Indicators weights		
Policy number	Policy focus	Wheat CWP	Sunflower CWP	WYLD
1	Balanced	0.25	0.25	0.50
2	Agricultural	0.4	0.4	0.2
3	Water resources	0.1	0.1	0.8
4	Wheat production	0.8	0.1	0.1
5	Sunflower production	0.1	0.8	0.1

the sowing date is shifted 10 days earlier (ESD-10). The 20 days shift (ESD-20) was not very effective on the agricultural indicator as CWP decrease is expected on sunflower in both emission scenarios and on the one of wheat under RCP8.5.

On the other hand, both ESD-10 and ESD-20 strategies gave better results on hydrologic indicator compared to the NT strategy. Up to 3.8% (standard deviation of 0.40%) increase of the water yield is possible by applying the ESD-20 strategy under RCP4.5 scenario.

9.4. No tillage and sowing dates change strategies

This strategy aimed at checking the potential cross-effects of both no tillage (NT) and early sowing dates (ESD) under the emission scenarios considered. The results (Table 9) show that CWP of wheat is increased by 25% ± 2.30 and 18.5% ± 5.98 in RCP5.4 and RCP8.5 respectively when NT and ESD-10 are applied. For sunflower, this strategy did not show any success. The NT and ESD-20 was not effective in overall and led to 40.6% (standard deviation of 11.89%) decrease of sunflower water productivity in RCP4.5.

The findings were different for the hydrologic indicator, positive effects on WYLD of NT + ESD-10 and NT + ESD-20 strategies were observed. The maximum water yield increase in this study was achieved by the strategy NT + ESD-20 under the RCP8.5.

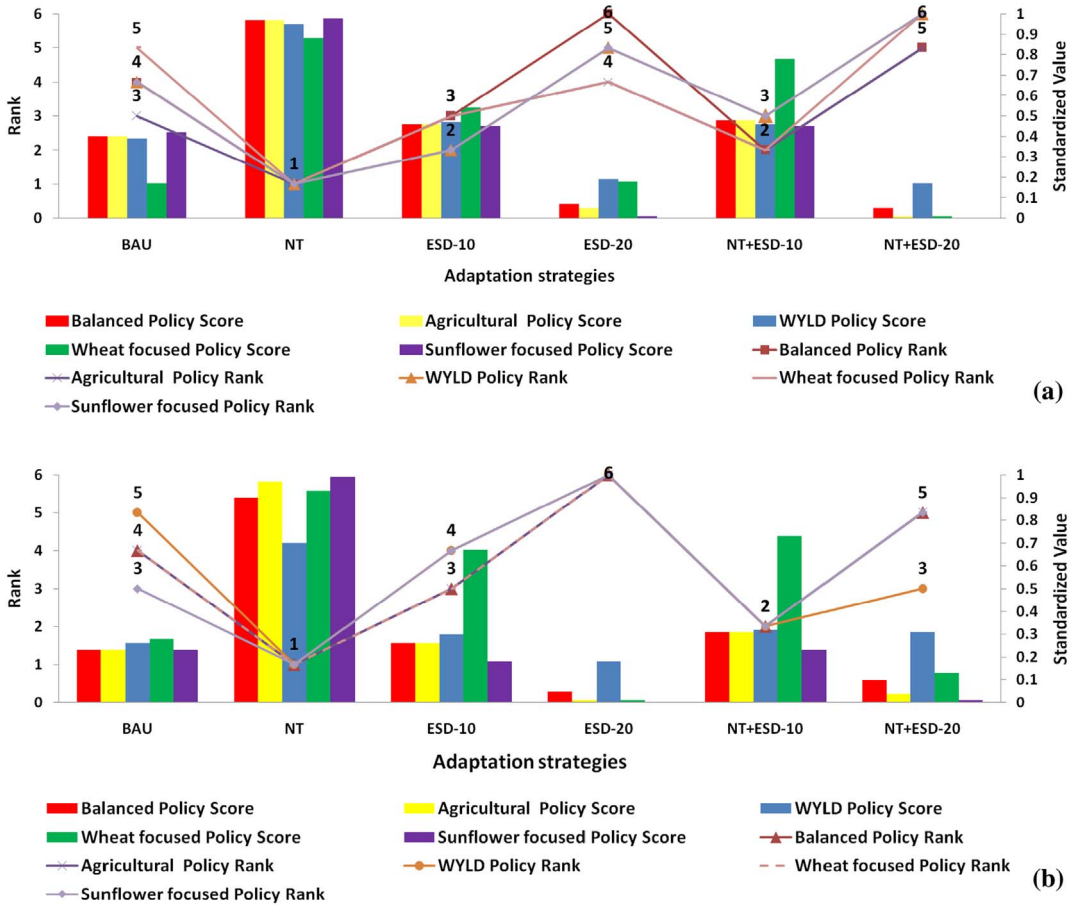

Fig. 3. Standardized values and ranking of adaptation strategies according to the management polices under (a) RCP4.5 and (b) RCP8.5.

10. Adaptation strategies comparison

By ranking the different adaptation strategies, five different watershed management policies were reviewed using TOPSIS technique and by changing weights of the considered indicators (CWPs and WYLD).

Table 10 represents the justification of different management policies and the weights of corresponding investigated indicators.

The Business as Usual (BAU) scenario was included in the strategies comparison to examine the rationale behind implementing the selected adaptation strategies against keeping the same situation during 2031–2050.

Fig. 3 indicate the ranking of the different adaptation strategies and show clearly that the NT strategy is the best adaptation strategy against climate change impact in study watershed under both RCP scenarios, whatever the focus of the management policy is. Indeed, changing weights of CWPs and WYLD indicators was always placing the no tillage strategy in the first rank.

The other adaptation strategies ranks were sensitive to the emission scenario and to the management policy focus. For the emission scenario RCP4.5, ESD-10 and NT + ESD-10 were generally dominating the ranks 2 and 3 suggesting that these two strategies may be effective strategies as well. Most of the very last ranks were taken either by ESD-20 or NT + ESD-20 strategies as the worst adaptation strategies to consider.

In the case of the emission scenario RCP8.5, the strategy NT + ESD-10 was the second-best adaptation strategy against the impact of climate change within the R'dom watershed in all different policies. ESD-20 was ranked the last in all management policies.

In both emission scenarios, The BAU has never been ranked first which outlines the importance of the implementation of adaptation strategies to make the farming activity in the study watershed more climate-smart against future climate change.

11. Conclusions

This study attempts to investigate the management of “What if” scenarios related to climate change impacts on water use efficiency and water availability in one of the representative semi-arid watersheds in the North-western part of Morocco. The results showed that:

- The SWAT model succeeded in replicating both hydrological process occurring in the study watershed and the crop yields.
- The R'dom watershed will experience significant changes of rainfall and temperatures patterns over the seasons in the period 2031–2050 under both RCPs 4.5 and 8.5.
- It is very important to implement sustainable adaptation strategies to preserve the water resources and increase rainfed crops water efficiency in the watershed.
- The no tillage strategy gave the best compromise between food security, water use efficiency and water resources in the watershed;
- Sowing 10 days earlier than usually offers good effectiveness in overall to overcome the climate change impacts in the future; combining this strategy with no tillage, gives very promising results as well.

This study aimed to give a general framework by focusing on two rainfed crops in the watershed due to their socio-economic importance in the study area and in other similar regions in the world, larger study scope (more crops) will definitely give more prominent effects of the adaptation strategies especially on the water yield indicator.

Although this study focused on R'dom watershed, the results are applicable for areas with similar characteristics and challenges. These results open a window for assessing other potential adaptation strategies, like: land use change scenarios, deficit irrigation for the irrigated crops… etc.

Only one GCM was used in this study due to its successful previous use in similar studies in Morocco and to the good results obtained during the bias correction; however the use of other GCMs is recommended for more deep comparison purposes.

Funding

This research did not receive any specific grant from agencies in the public, commercial, or not-for-profit sectors.

References

Aaron, R.M., Daniel, E.S., Stoecker, L.A., 2015. Using SWAT to simulate crop yields and salinity in the North Fork River Basin. USA Int. J. Agric. Biol. Eng. 8.
Abdelwahab, O.M.M., Bingner, R.L., Milillo, F., Gentile, F., 2016. Evaluation of alternative management practices with the AnnAGNPS model in the Carapelle watershed. Soil Sci. 181, 293–305. http://dx.doi.org/10.1097/ss.0000000000000162.
Abouabdillah, A., Oueslati, O., De Girolamo, A.M., Lo Porto, A., 2010. Modeling the impact of climate change in a Mediterranean catchment (Merguellil-Tunisia). Fresenius Environ. Bull. 19, 2334–2347.
Abouabdillah, A., White, M., Arnold, J.G., De Girolamo, A.M., Oueslati, O., Maataoui, A., Lo Porto, A., 2014. Evaluation of soil and water conservation measures in a semi-arid river basin in Tunisia using SWAT British Society of Soil Science. http://dx.doi.org/10.1111/sum.12146.
Aboudrar, A., Bouaziz, A., Debaek, P., Chekli, H., 2004. Effect of Tillage on Crop Establishment, Yield and Water Use of Sunflower in Rainfed Conditions of Meknes. Morocco. Paper presented at the International Sunflower Conference, Fargo, USA.
Ait Houssa, A., Oubaki, L., Reda-Fathmi, K., Drissi, S., Lamghari, M., Benbella, M., Chraibi, H., 2014. Réussir la culrure du blé tendre en bour vol 61/99. Moroccan Minister of Agriculture, Rabat.
Amengual, A., Homar, V., Romero, R., Alonso, S., Ramis, C., 2012. A statistical adjustment of regional climate model outputs to local scales: application to Platja de Palma, Spain. J. Clim. 25, 939–957. http://dx.doi.org/10.1175/jcli-d-10-05024.1.
Arnold, J.G., Kiniry, J.R., Srinivasan, R., Williams, J.R., Haney, E.B., Neitsch, S.L., 2011. Soil and Water Assessment Tool Input/Output File Documentation-Version 2009. Texas Water Resources Institute Technical Report 365.
Arnold, J.G., et al., 2012. SWAT: model use. Calibration, and Validation Am. society of Agriculture and Biological Engineers 55, 1491–1508.
Balaghi, R., 2014. Evaluation de la Productivité de l'eau en Agricultures Pluviales et Irriguées au Maroc. Food and Agriculture Organization, Rome.
Balaghi, R., 2017. Le changement Climatique Dans la Region de Fes-Meknes. (Rabat).
Balaghi, R., Dahan, R., 2015. Potentialités D'adaptation et D'atténuation au Maroc.
Balaghi R, Mohammed J (1993) Blé tendre Amal. (Accessed June 2017).
Bamouh, A., 1993. Fiche Technique: La Culture du Tournesol vol 44. (Rabat).
Bamouh, A., El Asri, M., Bouaziz, A., 2001. Potentialités des Cultures Oléagineuses Hivernales vol 85. Transfert de Technologie en Agriculture-PNTTA.
Bouignane, A., 2010. Sechresse dans le bassin du Sebou: Etat actuel et perspectives. (Madrid).
Bourarach, E.H., Bouzza, A., Nousfi, A., 1998. Developpement d'un systeme d'enterrage de semoir direct pour le travail en sol sec Homme Terre Eaux. 28. pp. 5–10.
Brouziyne, Y., Abouabdillah, A., Benaabidate, L., 2017a. Water balance modeling under climate change impact in a Mediterranean watershed; Case of R'dom, Morocco. In: Benaabidate, D.I.K.D.U.D.Y.D.L. (Ed.), Ecology, Planning and Design. ST. Kliment Ohridski University Press, Sofia, pp. 396–406.
Brouziyne, Y., Abouabdillah, A., Bouabid, R., Benaabidate, L., 2017b. SWAT streamflow modeling for hydrological components' understanding within an agro-sylvo-pastoral watershed in Morocco. J. Mater. Environ. Sci. 9.
Bucak, T., et al., 2017. Future water availability in the largest freshwater Mediterranean lake is at great risk as evidenced from simulations with the SWAT model vol 58. http://dx.doi.org/10.1016/j.scitotenv.2016.12.149.
Ceglar, A., Kajfez, B., 2011. Simulation of maize yield in current and changed climatic conditions: addressing modelling uncertainties and the importance of bias correction in climate model simulations. Eur. J. Agron. 37, 83–95. http://dx.doi.org/10.1016/j.eja.2011.11.005.
De Gerolamo, A.M., Gallart, F., Pappagallo, G., Santese, G., Lo Porto, A., 2015. An eco-hydrological assessment method for temporary rivers. The Celone and Salsola rivers case study (SE, Italy) Annales de Limnologie. Int. J. Limnol. 51, 1–10.
De Gerolamo, A., Barca, E., Pappagallo, G., Lo Porto, A., 2016. Simulating Ecologically Relevant Hydrological Indicators in a Temporary River System Agricultural Water Management.
Debaek, P., Casadebaig, P., Flenet, F., Langlande, N., 2016. Sunflower crop and climate change: vulnerability, adaptation, and mitigation potential from case-studies in Europe Oilseeds & fats crops and lipids. 25. pp. 1–15.
DPA, 2017. Les rendements des cultures bours dans la région de Meknes. MAPM, Meknes.
El Gherras, O., Idrissi, M., 2006. Contraintes technologiques au developpement du semis direct au Maroc Options Médietrraneenes. 69. pp. 121–124.
Eltigani, E.B.A., 2015. Sowing dates and crop replacements strategies to adapt climate change impact on traditional rainfed agriculture in semi arid regions: a case of North Kordofan in Sudan. Int. J. Sudan Res. 5.
FAO, 2013. Climate-Smart Agriculture Sourcebook. (Rome).
Feyereisen, G., Strickland, T., Bosch, D., Sulivan, D., 2007. Evaluation of SWAT manual calibration and input parameters sensitivity in the Little River watershed. Am. Soc. Agri. Biol. Eng. 50, 843–855.

Fischer, R.A., 1979. Growth and water limitation to druland wheat in Australia: a physiological framework. J. Aust. Inst. Agric. Sci. 45, 83–94.
Gimeno, V., Fernandez-Martinez, J.M., Fereres, E., 1989. Winter planting as a means of drought escape in sunflower. Field Crop Res. 22, 307–316.
Grafton, R.Q., Williams, J., Jiang, Q., 2015. Food and water gaps to 2050: preliminary results from the global food and water system (GFWS) platform. Food Security 7, 209–220. http://dx.doi.org/10.1007/s12571-015-0439-8.
Grimaldi, S., et al., 2015. 2.18 - statistical hydrology A2 - wilderer, peter. In: Treatise on Water Science. Elsevier. Oxford, pp. 479–517. http://dx.doi.org/10.1016/B978-0-444-53199-5.00046-4.
Haan, C.T., Allred, B., Storm, D.E., Sabbagh, G.J., Prabhu, S., 1995. Statistical procedure for evaluating hydrology/water quality models. Trans. ASAE 38 (3), 725–733.
HCP, 2011. Activite, emploi et chomage. Resultats detaille de 2011. (Rabat).
Hirich, A., Choukr-Allah, R., Ragab, R., Jacobsen, S.E., 2012. The SALTMED model calibration and validation using field data from Morocco. J. Mater. Environ. Sci. 3, 342–359.
Hwang, C.L., Yoon, K., 1981. Multiple Attribute Decision Making: Methods and Applications. (New York).
Hwang, S., Graham, W.D., Geurink, J.S., Adams, A., 2013. Hydrologic implications of errors in bias-corrected regional reanalysis data for west central Florida. J. Hydrol. 510, 513–529. http://dx.doi.org/10.1016/j.jhydrol.2013.11.042.
Jaw, T., Li, J., Kl, Hsu, Sorooshian, S., Driouech, F., 2015. Evaluation for Moroccan dynamically downscaled precipitation from GCM CHAM5 and its regional hydrologic response vol 3. http://dx.doi.org/10.1016/j.ejrh.2015.02.008.
Jlibene, M., 2009. Amelioration genetique du ble tendre. Institut National de Recherche Agronomique, Rabat.
Jun, K.S., Chung, E.-S., Sung, J.-Y., Lee, K.S., 2011. Development of spatial water resources vulnerability index considering climate change impacts. Sci. Total Environ. 409, 5228–5242. http://dx.doi.org/10.1016/j.scitotenv.2011.08.027.
Kang, Y., Khan, S., Ma, X., 2009. Climate change impacts on crop yield, crop water productivity and food security â€ A review. Prog. Nat. Sci. 19, 1665–1674. http://dx.doi.org/10.1016/j.pnsc.2009.08.001.
MAPM (2013) L'agriculture Marocaine en chiffres. (Accessed August 2017).
Maraun, D., 2013. Bias correction, quantile mapping, and downscaling: revisiting the inflation issue. J. Clim. 26, 2137–2143. http://dx.doi.org/10.1175/jcli-d-12-00821.1.
Moriasi, D.N., Arnold, J.G., Van Liew, M.W., Binger, R.L., Harmel, R.D., Veith, T., 2007. Model evaluation guidlines for systematic quantification of accuracy in watershed simulations in watershed simulations. Trans. ASABE 50, 885–900.
Moriasi, D.N., Wilson, B.N., Douglas-Mankin, K.R., Arnold, J.G., Gowda, P.H., 2012. Hydrologic and water quality models: use, calibration, and validation. Trans. ASABE 55, 1241–1247.
Mrabet, R., 2001. Wheat yield and water use efficiency under constrasting residue and tillage management systems in a Semiarid area of Morocco. Exp. Agric. 38, 237–248.
Mrabet, R., Moussadek, R., Fadlaoui, A., Van Ranst, E., 2012. Conservation agriculture in dry area of Morocco. Field Crop Res. 132, 84–94.
Neitsch, S.L., Arnold, J.G., Kiniry, J.R., Williams, J.R., King, K.W., 2002. Soil & Water Assessment Tool-Theoretical Documentation - Version 2000 Grassland. 76502 Soil and Water Research Laboratory-Agricultural Research Service, Temple-Texas, US.
Ons, O., De Gerolamo, A.M., Abouabdillah, A., Kjeldsen, T., Lo Porto, A., 2015. Classifying the flow regimes of Medietrranean streams using multivariate analysis. Hydrol. Process. 29, 4666–4682.
Pascual, D., Pla, E., Fons, J., Abdul-Malak, D., 2017. Climate change impacts on water availability and human security in the intercontinental biosphere reserve of the mediterranean (Morocco-Spain). In: Behnassi, M., McGlade, K. (Eds.), Environmental Change and Human Security in Africa and the Middle East. Springer International Publishing, Cham, pp. 75–93. http://dx.doi.org/10.1007/978-3-319-45648-5_4.
Passioura, J.B., 1977. Grain yield, harvest index, and water use of wheat Journal of the Australian Institute of Agricultural Science. 43. pp. 37–75.
Piani, C., Weedon, G.P., Best, M., Gomes, S.M., Viterbo, P., Hagemann, S., Haerter, J.O., 2009. Statistical bias correction of global simulated daily precipitation and temperature for the application of hydrological models Journal of Hydrology. 395. pp. 199–215. http://dx.doi.org/10.1016/j.jhydrol.2010.10.024.
Rathjens, H., Bieger, K., Sriniviasan, R., Chaubey, I., Arnold, J.G., 2016. CMhyd User Manual. (Texas).
Rezaei Zaman, M., Morid, S., Delavar, M., 2016. Evaluating climate adaptation strategies on agricultural production in the Siminehrud catchment and inflow into Lake Urmia, Iran using SWAT within an OECD framework vol 147. http://dx.doi.org/10.1016/j.agsy.2016.06.001.
Sang-Mook, J., Eun-Sung, C., Yeonjoo, K., Sang-ho, L., 2013. Prioritizing the best area for treated Wastwater use using RCP 8.5. J. Environ. Prot. 4, 56–61.
Senatore, A., Mendicino, G., Smiatek, G., Kunstmann, H., 2010. Regional climate change projections and hydrological impact analysis for a Mediterranean basin in Southern Italy. J. Hydrol. 399, 70–92. http://dx.doi.org/10.1016/j.jhydrol.2010.12.035.
Shi, P., et al., 2011. Evaluating the SWAT model for hydrological modeling in the Xixian watershed and a comparison with the XAJ model. Water Resour. Manag. 25, 2595–2612. http://dx.doi.org/10.1007/s11269-011-9828-8.
Si Bennasseur, A., 2014. Referentiel pour la conduite technique de la culture du ble tendre. Fellah Trade 22, 10–23.
Sinnathamby, S., Douglas-Mankin, K.R., Craige, C., 2016. Field-scale calibration of crop-yield parameters in the Soil and Water Assessment Tool (SWAT) vol 180, Part A. http://dx.doi.org/10.1016/j.agwat.2016.10.024.
Srinivasan, R., Zhang, X., Arnold, J.G., 2010. SWAT ungauged: hydrological budget and crop yield prediction in the upper Mississippi river basin. Am. Soc. Agri. and Biol. Eng. 53, 1533–1546.
Steduto, P., Hsiao, T.C., Fereres, E., Raes, D., 2012. Crop yield response to water. In: Exchange Ook (ed) FAO Irrigation and Drainage Paper. FAO Publications, (Rome).
Teutschbein, C., Seibert, J., 2012. Bias correction of regional climate model simulations for hydrological climate-change impact studies: review and evaluation of different methods. J. Hydrol. 457, 12–29. 456â€. https://doi.org/10.1016/j.jhydrol.2012.05.052.
Tramblay, Y., Ruelland, D., Somot, S., Bouaicha, R., Servat, E., 2013. High-resolution Med-CORDEX regional climate model simulation for hydrological impact studies: a first evaluation of the ALADIN-Climate model in Morocco. Hydrol. Earth Syst. Sci. 17, 3721–3739.
Turner, N.C., 1997. Further progress in crop water relations. Adv. Agron. 58, 293–338.
Ullrich, A., Volk, M., 2009. Application of the Soil and Water Assessment Tool (SWAT) to predict the impact of alternative management practices on water quality and quantity. Agric. Water Manag. 96, 1207–1217. http://dx.doi.org/10.1016/j.agwat.2009.03.010.
UN, 2017. World Population Prospects. (United Nations).
Van Liew, M.W., Arnold, J.G., Bosch, D., 2005. Problems and potential of autocalibrating a hydrologic model. Trans. ASABE 48, 1025–1040.
Villalobos, F.J., Fereres, E., 1990. Evaporation measurements beneath corn, cotton, and sunflower canopies. Agron. J. 82, 1153–1159.
Waidler, D., White, M., Steglich, E., Wang, S., WIilliams, J., Jones, C., Srinivasan, R., 2011. Conservation Practice Modeling Guide for Swat and Apex Texas Water Resources Institute.
Zian, A., 2011. Hydrologie, Qualité des eaux de surface et des sédiments er Géochimie des eaux thermales du bassin versant de R'dom, region des Rides Sud Rifaines University of Tuscany-Italy Université Sidi Mohamed Ben Abdellah-Faculté des Sciences et Techniques. Laboratoire de Georesources et environnement.
Zwart, J.S., 2010. Benchmarking Water Productivity in Agriculture and the Scope for Improvement. University of Delft.